Future Aviation Data Link Technologies for Weather Dissemination June 2, 2004

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WINCOMM Goal

Develop advanced communications and information technologies to enable the high quality and timely dissemination of strategic weather information between the flight deck and ground users/providers.

Objective and Approach

Objective

- WINCOMM has a number of key areas which have been identified that are a lower TRL in technology where appropriate investment will provide the necessary incentive and payback in TRL advancement.

Approach

- These efforts are component technologies being developed through partnerships with industry and academia providing the cost benefit, performance requirements, and schedule while insuring a path to industry transfer including implementation.
- OAI under a cooperative agreement with NASA-GRC has established, technical leads and manages an Aviation Datalink Research Group for these activities and partnerships.

Development Path and Technologies

Development Path

- System Developments
- Component Solutions
- Development Plans
- Proof of Concepts

Technologies/Products

- Aviation Cellular
- ESCAN
- Radio-on-a-Chip
- Compression and Gridding

Aviation Cellular (AvCell)

Cellular communication architectures and technologies research for use by aviation is focused on the identification of the technology gaps and shortfalls, defining and understanding the issues preventing current use in the cockpit. Data capabilities that cellular systems/networks would provide if implemented would greatly enhance the data-link capacity and performance for informational and advisory data, while considerably reducing cost through leveraging of the broad cellular user base.

Forward Path (Ground-Air): A key capacity driver is the FIS Products, providing strategic weather and National Airspace System (NAS) status information to pilots for strategic decision-making in the cockpit during the en-route phase of flight.

Return Path (Air-Ground): Serves two purposes, first for the dissemination of on-board sensor and telemetry information to the ground users for enhancing forecasting and weather products. Secondly providing the pilot a means for the request of FIS products to be sent to the cockpit.

AvCell Users/Operation

- This effort is focused on three aircraft classes:
  - Commercial/Business Aviation
    - Multi-user cellular device
    - Altitudes of 18,000 - 40,000 ft
    - Speeds up to 600 MPH.
    - Variable number of phones and data sets/ports is required for both cockpit and cabin use.
  - General Aviation
    - Single-user cellular device
    - Altitudes of 5,000 – 18,000 ft
    - Speeds not exceeding 250 MPH.
    - Single phone with a single data set/port
  - Cargo Carriers.
    - Single-user cellular device
    - Altitudes of 5,000 – 40,000 ft
    - Speeds up to 600 MPH
    - Single phone with a single data set/port

AvCell Performance/Capabilties

AvSP-WxAP: Weather Information Communications

Calls Rejected by the Network – Rejected calls for reasons of operational capacity or system failure, less than 5% of all call attempts.

Completed Call Setup - Successful deliver of 95% of all call initiation attempts user.

Hand-Off - Hand-offs will not be detectable to the called and/or calling parties for 99.9% of all completed calls.

Dropped Calls – No more than 5% of calls will be dropped inadvertently.

Time to Initiate a Call - Time between call initiation and the call request being delivered will be less than 3 seconds for 95% of all successful call attempts.

Call Indication - Incoming call notification will occur within 3 seconds of a call request being received by the base station of the cellular network communicating with the aircraft.

Messaging - Mobile messaging, SMS, EMS and MMS, technologies and services will be available to and from the aircraft over the cellular network.

Data Rate - All calls will be provided a minimum data rate of 64Kbps per call, which will be maintained for the duration of the call.

Bit Error Rate - Calls established will maintain a minimum bit error rate of 5*10-7 for the duration of the call.

AvCell Propagation

Cellular networks currently deployed are optimized using 2 dimensional models maximizing and optimizing ground coverage for the mobile ground user, while minimizing interference. Methods employed to minimize this interference include:

- Antenna down-tilt
- Sector Antennas
- Dynamic Power Control

Cellular base station in their current configuration from the perspective of an airborne transceiver at altitude in a 3 dimensional environment is required. Modeling of base stations with typical antennas, power levels and tilts is being conducted establishing coverage patterns from surface through 40,000 ft. Propagation characteristics are crucial in finalizing an approach and the associated component specifications for development of the proof of concept units/devices.

Phase 1: Define existing cellular systems/networks with no modifications.

Phase 2: Define existing cellular systems/networks with an antenna augmentation at selected cellular ground stations.

Phase 3: Develop/define a relay/stretched network concept bridging the existing cellular network with an airborne cellular network.

Phase 4: Propagation Flights over 2 US cities validating modeling performed.

ESCAN

Development and validation of a proof concept (POC) wideband electronically scanned reconfigurable array (ESCAN)

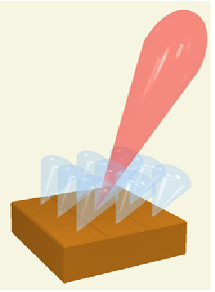
- 5x1 Array with a 20 pad x 20 pad element
- Performance:
  - Bandwidth: 800MHz -2.6GHz
  - 5 x 1 Array Broadside Gain: 19dB @ 2.4GHz
  - 1-5 Independent Beams
  - Steering: +/-70 deg
  - Power Handling: 1W CW per feed at 2.4GHz
  - Reconfiguration Time: 20 usec
- Depending on phased array performance electronically scanned arrays range between $100K - $300K. ESCAN production costs are 1-2 orders of magnitude LESS regardless of the process utilized.

Basic Features of Reconfigurable Elements

- **A Structural Design that Enables the Radiator to Electrically Evolve**
  - High capacity to vary element shape and resonant length scales
    - Antennas that switch a limited number of radiators in and out are often referred to as "Smart or Adaptive" and have more restricted performance
  - A design which allows for broadband impedance matching capability
    - Maximizes bandwidth and gain
    - Improves beam steering capability with a single feed
- **Embedded Control Electronics**
  - Deliver power and reconfiguration instruction into the aperture
  - Minimize electromagnetic interference with the radiative function (no conductive wires)
  - Maintain the current distribution integrity through the aperture
  - Enable fast reconfiguration times
    - Facilitates tracking

ESCAN

Benefits of Reconfigurable Elements/Arrays

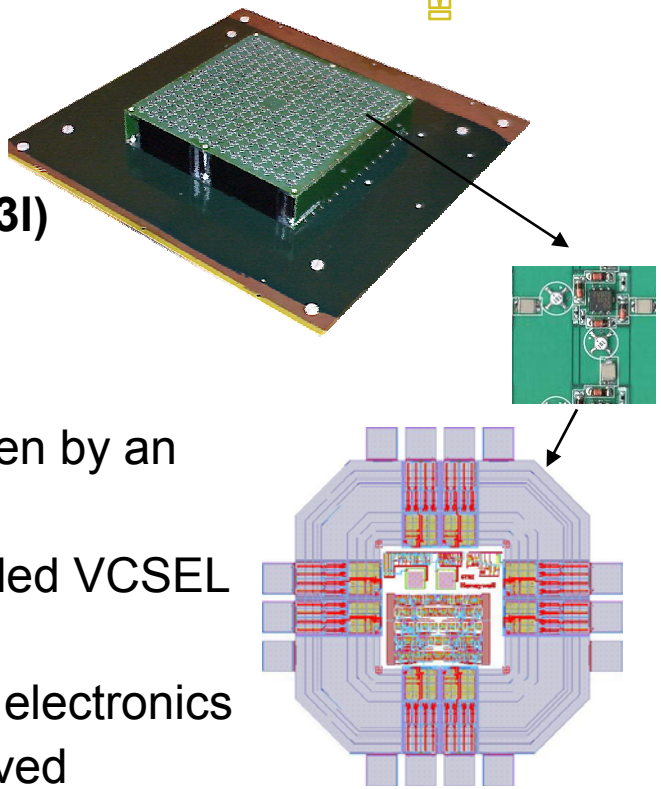


Reconfigurable Aperture

- **Multifunctional Aperture**
  - Possesses weight, cost, and signature reduction benefits
- **Adapts to the External Communication Environment**
  - Null steering for anti-jamming capability
  - Enables gain for bandwidth trades
- **Single Feed Steering**
  - Reconfigurable structures permit steering at frequencies above the grating lobes without the immediate loss in gain experienced in phased array concepts.
- **Low Observables**
  - During periods when the antenna functionality is not required the reconfigurability of the aperture may be utilized to force the structure to function as R-card for signature reduction.

ESCAN

- **ESCAN: 800MHz-2.6GHz 5x1 Reconfigurable Array**
- **Structural Form of the Element**
  - –Utilizes a proven reconfigurable element concept developed at Georgia Tech (GTRI)[2]
  - –Funded by DARPA RECAP/ FCS-C Programs
    - GTRI RECAP **Bandwidth: 500MHz-2.7GHz**
    - GTRI RECAP **Directive Gain: 14dB (1.3l X 1.3l)**
    - GTRI RECAP **Beamsteer: +/-55°**

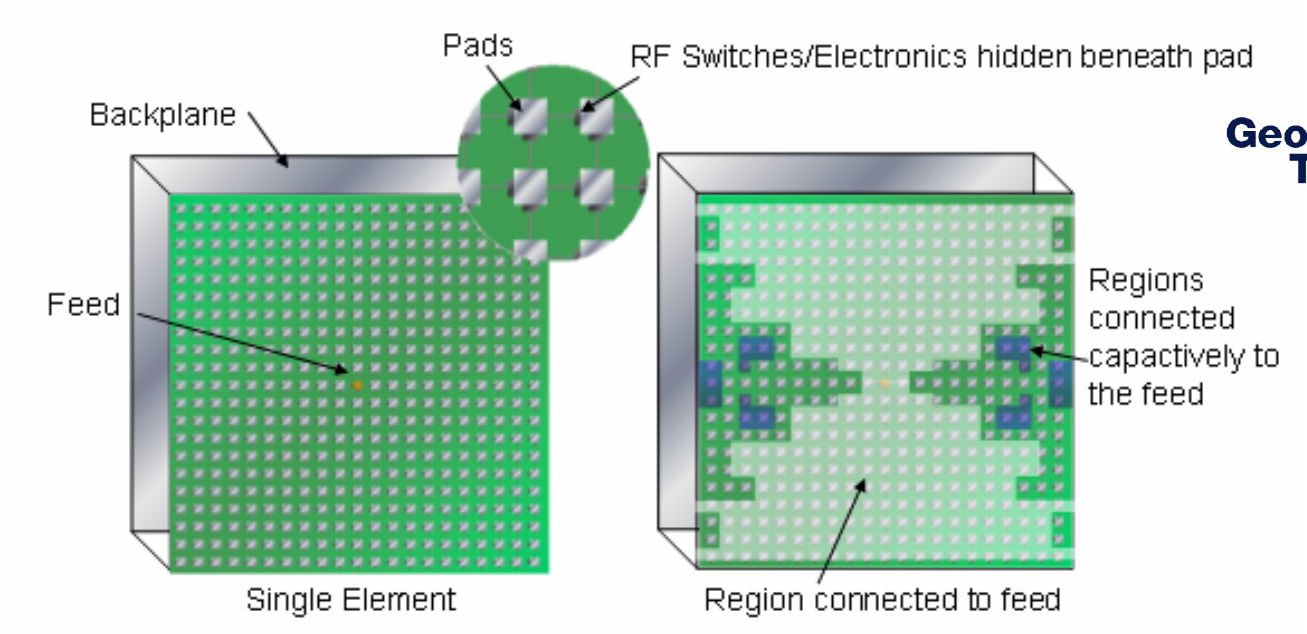


- **Embedded Control Electronics**
  - –Utilizes a Honeywell electronics design solely driven by an optical interface
    - Optical backplane is composed of DSP controlled VCSEL array
    - ASIC development for the embedded aperture electronics
    - Power efficient economical solution with improved manufacturability

1.J. C. Maloney, M.P. Kesler, L. M. Lust, L.N. Pringle, T. L. Fountain, P. H. Harms, G.S. Smith,
" Switched Fragmented Aperture Antennas", IEEE Antennas Propagat. Soc. Int. Symposium,, vol 1, pp. 310-313, July 2000.

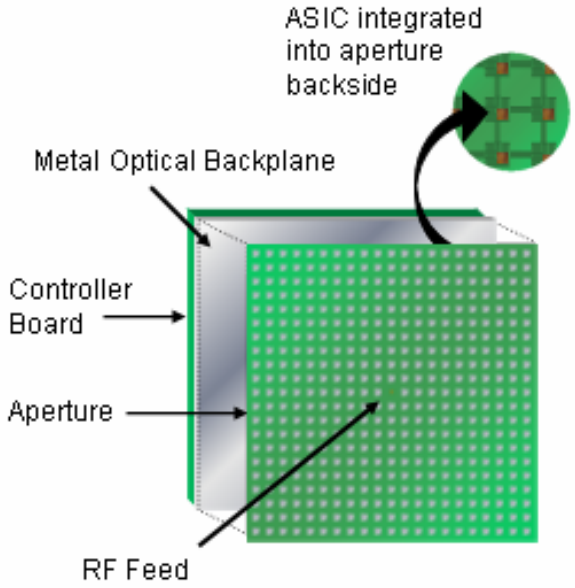
ESCAN

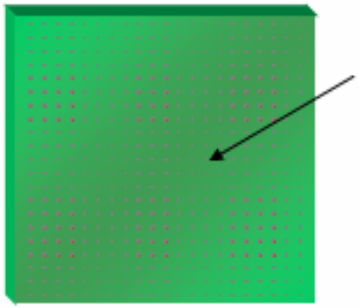
- **ESCAN's Structural Form is Based on GTRI RECAP**
- **The radiative pattern generated from a single feed element may be reconfigured by connective switches located between each pad.**
  - –Individual pads<< l and are not resonate alone
  - –Collectively the pads connected to the feed generate a radiating form.
  - –The parasitic pads capacitively coupled to the feed may be configured to improve matching characteristics enabling wider band performance.



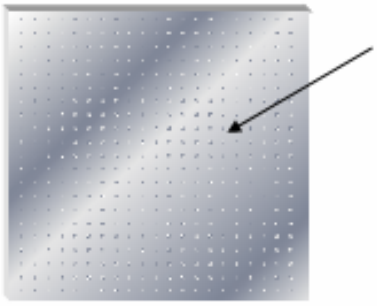
ESCAN

- **ESCAN: Honeywell's Embedded Controls**
  - **Power efficiency enables pure optical interface**
    - ASIC embedded behind each pad contains a photocell and RF switch
    - VCSEL array is situated on a PCB behind the antenna ground plane
    - VCSEL array is controlled by 1 DSP/microcontroller per element

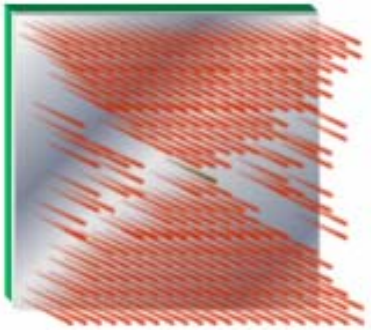




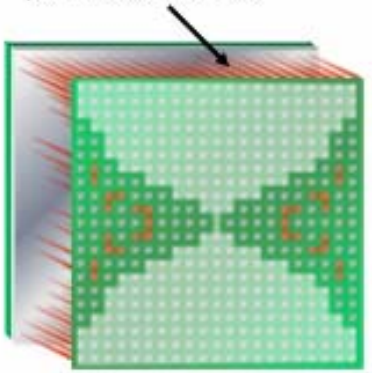
Controller board contains VCSEL die on the front and interface wiring on the back connected to a microcontroller or DSP.



An array of holes is cut into optical black plane. To permit the VCSEL beam to focus on to the ASICs.

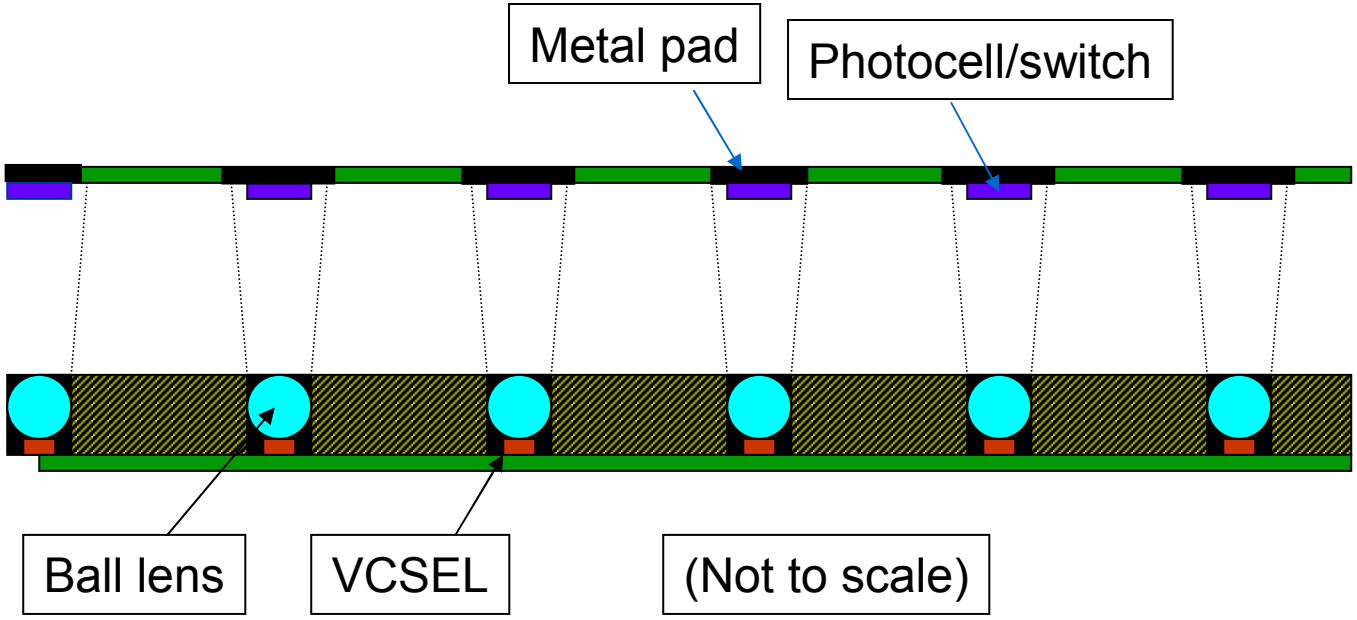


Emitting VCSELs focused at photocells in ASIC



ESCAN

- **ESCAN ASIC Development**
- ASIC includes 2 RF switches and photodetector (PD)
- Switch insertion loss needs to be minimized and isolation maximized for good power handling and antenna gain
- VCSEL output is concentrated on photocell array to maximize photocurrent and switching speed



ESCAN

- **ESCAN Program Goals**
  - Bandwidth: 800MHz -2.6GHz
  - Element Broadside Gain: 13dB @ 2.4GHz and 7dB @ 900Mhz
    - Theoretical Aperture Gain=$4p/l^2$=17dB
  - 5 x 1 Array Broadside Gain: 19dB @ 2.4GHz and 13dB @ 900Mhz
  - Element Broadside Beamwidth: 32deg @ 2.4GHz 85deg @ 900MHz
  - Array Broadside Beamwidth: 4.5deg @ 2.4GHz 12deg @ 900MHz
  - Steering: +/-70 deg
    - Controlled by pad density and the insertion form factor of the array
  - Power Handling: 1W CW per feed at 2.4GHz
    - Switch dependent
  - Reconfiguration Time: 20 usec
    - Dependent on photocell
  - Production cost: Significant reduction from electronically scanned arrays
  - Ease of Manufacture

Radio on a Chip (ROC)

- **Initial target is low cost devices**
  - cost sensitive market
  - widest possible ranges of users
    - EFB - Air Transport
    - Low cost NEXCOM transceiver - General Aviation
  - graduate to expanded markets with later designs
- **Battery operation**
  - independent of aircraft systems
- **Target operating range is 50MHz to 450MHz**
  - Covers marker beacon, comm, nav, ILS, glideslope, & MilCom bands
    - larger application market means lower per-unit costs
- **Present design targets for VDL applications**
  - Present IIP3 point is too low for fully certified NEXCOM communications products
  - Future designs will address higher degrees of certification

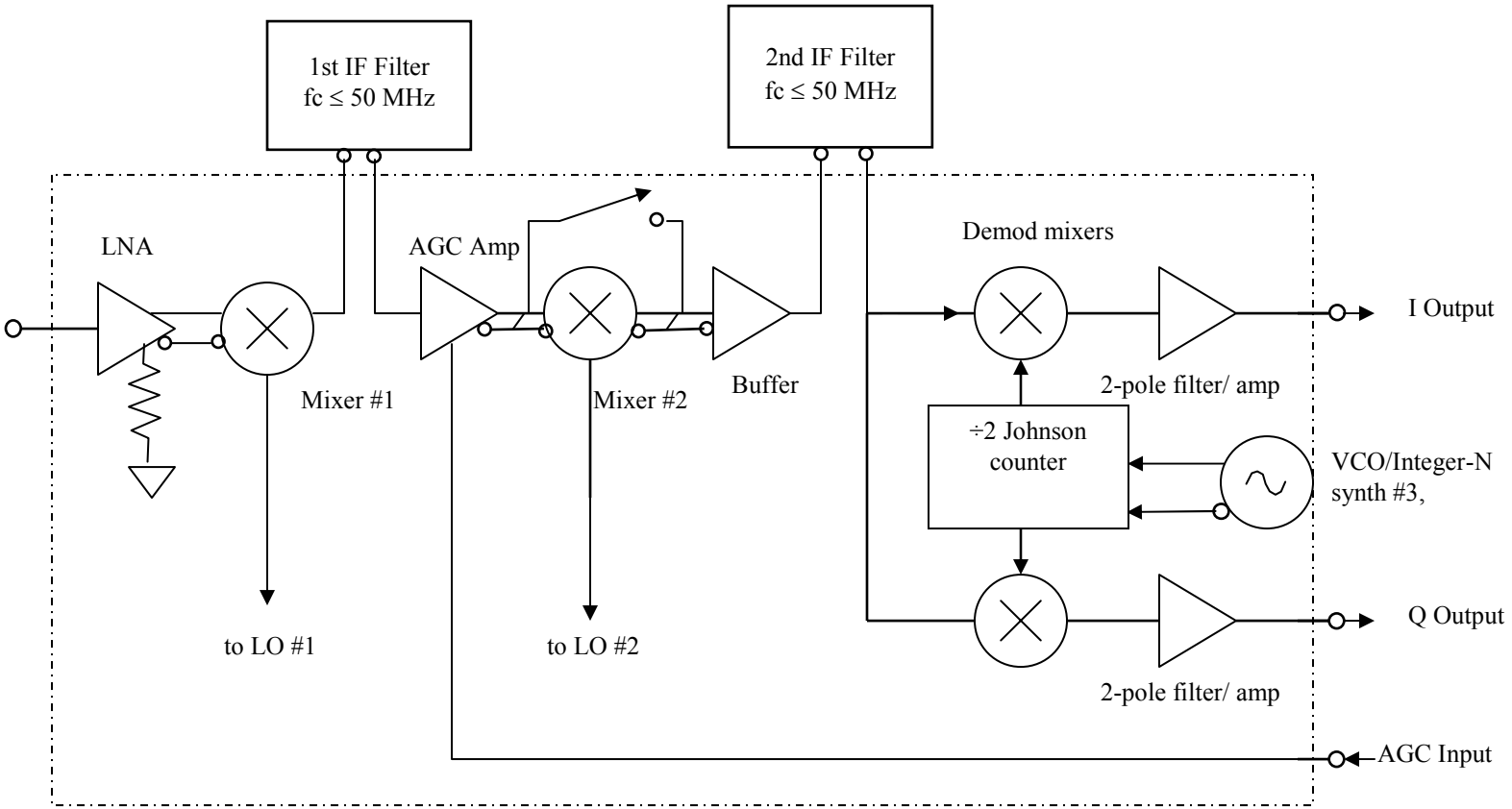
Rationale for ROC

- **Commercial communications system components increasingly focussed on cellular telephone technology.**
  - Larger market than general purpose radio circuits
  - Many traditional sources of generic radio components have quit the market.
  - General purpose radio chip market is too small & profits too limited to appeal to most chip vendors
- **Bring technology into the Aeronautical sector**
  - Reduces issues with obsolescence
    - reduces product life cycle costs
- **Custom designs tailored to specific applications**
  - Designed specifically for avionics market
- **Reduced component counts are possible**
  - Highly integrated designs mean fewer external components

Rationale for ROC

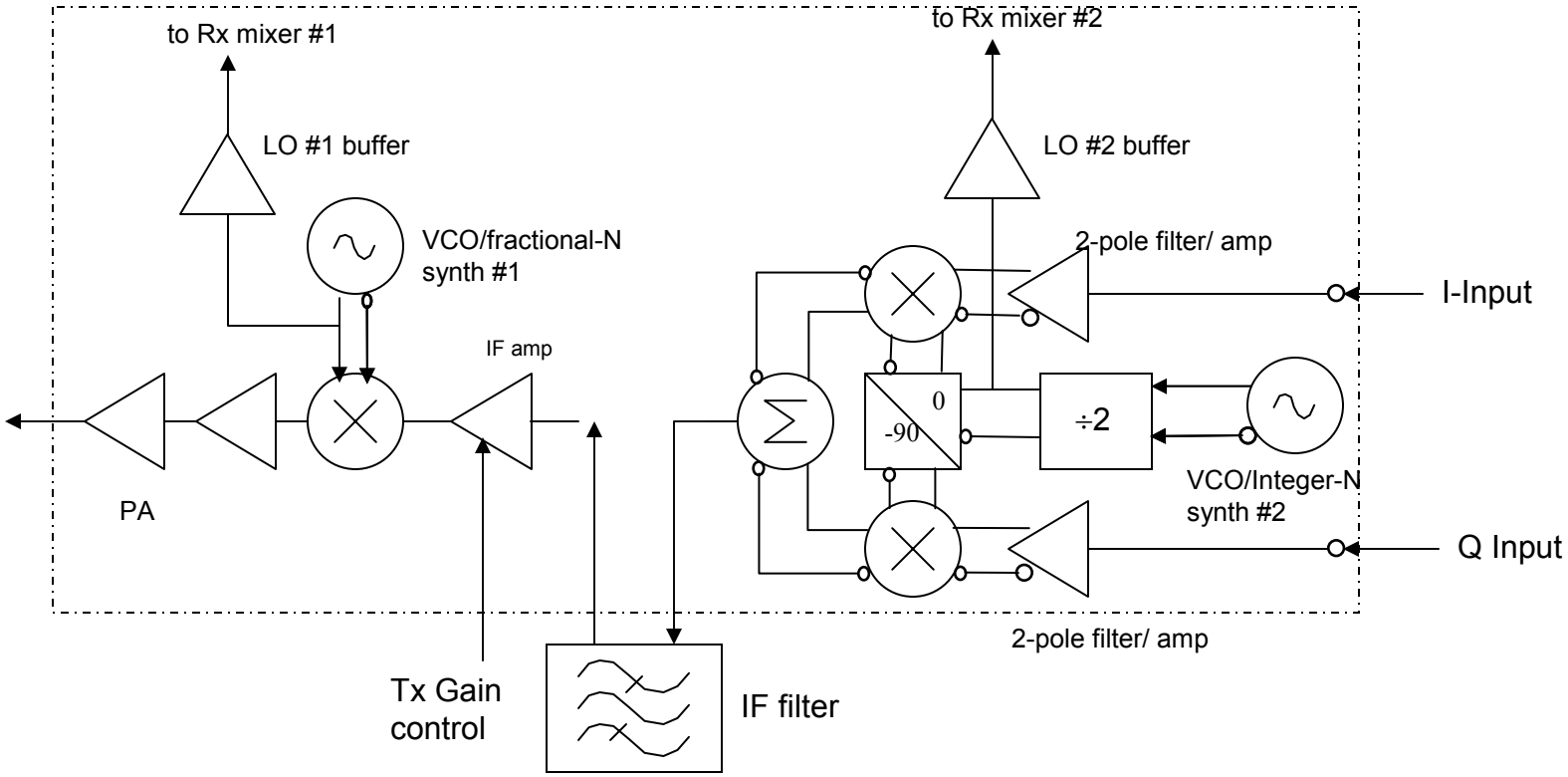
- **Control obsolescence**
  - Dependence on vendor removed
- **Control performance parameters**
  - Able to tailor performance to your requirements
- **Expensive to create**
  - Design costs typically exceed $1M
- **Limited markets**
  - Some compromises may be required to increase the market for the design (cost spreading)
  - Per unit costs may run higher than commercial components
- **Dependence on foundry process cycles**
  - Process for making the chip can go obsolete

Radio on a Chip Architecture



Receiver

Radio on a Chip Architecture



Transmitter

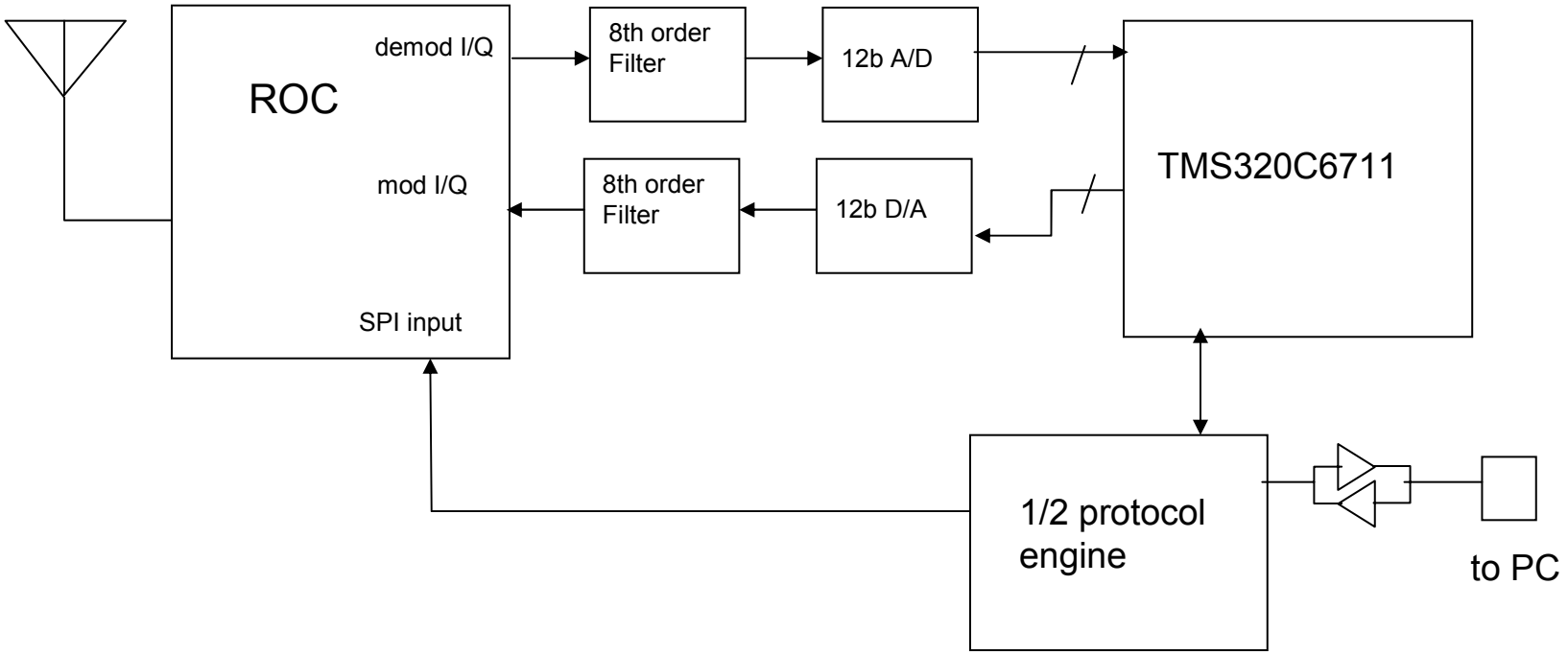
Radio on a Chip Architecture

- **Super-heterodyne single/double (switchable) conversion receiver**
  - Can be used in either single or double conversion mode
  - Higher performance than direct conversion receivers
  - Better noise figure than direct conversion receivers
  - Higher IP3 point than direct conversion systems
- **Why not a more software defined design?**
  - Software defined radios are extremely flexible
  - Can adapt to new modulation types with firmware modifications
  - Significant designer control over performance
  - Software radios cost point is higher
  - Maturity of the technology
  - Too power hungry for battery powered applications
    - ill suited to low power applications.

Radio on a Chip Architecture

- **Analog I/Q demodulator**
  - Lower overall power consumption than digital down-conversion and demodulation
  - Uses Johnson counters for nearly perfect I/Q LO generation
- **Three integrated local oscillators**
  - external tank and tuning components required.
- **Fully integrated synthesizers for all LO's**
  - Integer-N designs for the 2nd & 3rd LO
  - Fractional-N for the 1st LO
    - Offers improved LO noise vis-à-vis integer-N designs
    - Faster frequency switching than integer-N synthesizers.

ROC System Architecture



Transceiver architecture is very simple

ROC Application Demonstration

- **Data links can provide rich and varied information**
- **Bidirectional data links allow the pilot to request specific information not otherwise available**
- **VDL mode-3 data link**
  - Pressing need to get better information to pilots
  - Better info improves flight safety
  - Weather is a significant cause of fatal accidents

Demonstration radio is intended to prove a concept, leading to a product

ROC Application Demonstration

Would you rather have this?

2004/04/06 17:20 KBJI 061720Z 061818 33012KT P6SM SKC
FM0000 VRB06KT P6SM SCT250 FM0800 15007KT P6SM
SCT120 TEMPO 1115 BKN080 FM1500 18007KT P6SM
BKN080 PROB30 1518 -RA OVC030

Or, would you prefer this:

A picture just might be worth more than 1000 words...

ROC Conclusion

- **Radio-on-a-chip can tailored to meet specific requirements**
  - Product life-cycle costs can be significantly reduced
  - High initial cost requires careful consideration in deciding to design your own chips
- **High levels of integration are possible**
  - results in potentially significant reductions in circuit board complexity

Compression and Gridding

- **Phase 1: Survey and Modeling**
  - Prepare the basis for the design and implementation of the proposed compression algorithm.
- **Phase 2: Design and Implementation**
  - Devise the compression software and finalize the data repository.
- **Period 3: Test and Integration**
  - Test, evaluate and integrate the compression software.

Phase 1: Survey and Modeling

Research Plan

- Survey
  - Current weather data formats
  - Prior Compression techniques for weather data
  - Identify potential directions to improve the quality
- Data Understanding
  - Collection of the Weather Data
  - Statistical analysis of the weather data for data compression
- Modeling
  - Design of theoretical models, that will serve as the basis for compression
  - Choose model by certain model selection criterion, eg MDL

Phase 1: Survey and Modeling

- Potential Solutions
  - Predictive Compression: design issues in applying to compress weather data
  - Transform based methods and progressive compression
  - Stack-run image coding

Completed Products:

- Research Survey summarizing the current approaches to weather data compression, their weaknesses and approaches for improvement.
- Initial design of models for weather data compression.

Phase 2: Design and Implementation

Research Plan:

- Finalize the weather database repository
- Design the compression software based on selected models
- Build a beta version library of software tools for weather data compression
- Integrate the database with the software library
- Initialize the testing on the data repository

Products:

- Complete design of the compression framework
- Beta Version of the compression software
- Initial test results on the quality of the software

Phase 3: Test and Integration

Research Plan

- Performance evaluating and tuning of the developed compression software
- Finalize the software toolkit and integrate with current weather data dissemination systems
- Detailed test comparison of proposed technique with other approaches including prior techniques
- Final documentation describing the project results and potential future directions.

Completed Products

- Software toolkit and intgration
- Technical report describing the project results and potential future directions.

Acknowledgments

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  - ESCAN
    - Dr Lisa M Lust, Honeywell Labs, Minneapolis MN
  - Radio on a Chip
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